

GERMANY/HONG KONG JOINT RESEARCH SCHEME
THE PROJECT REPORT
(for Project Completion)

Project Number: G_HK018/11

Title

Energy-Efficient Data Management with Novel Storage Technologies

Particulars

	Hong Kong team				German team	
Name of Project Co-ordinator (with title)	Prof. Jianliang Xu				Prof. Theo Härder	
Name of Co-Investigator (if any)	Dr. Haibo Hu					
Institution or Institutional affiliation	<input type="checkbox"/>	CityU	<input type="checkbox"/>	HKU	<input checked="" type="checkbox"/> University of <u>Kaiserslautern</u>	
	<input type="checkbox"/>	CUHK	<input type="checkbox"/>	HKUST		
	<input checked="" type="checkbox"/>	HKBU	<input type="checkbox"/>	LU		<input type="checkbox"/> Others: _____
	<input type="checkbox"/>	HKIEd	<input type="checkbox"/>	PolyU		
Other project team members (if any)					Yi Ou	

Funding Period

	1 st year	2 nd year (if applicable)
Start Date	Jan. 1, 2012	Jan. 1, 2013
Completion Date	Dec. 31, 2012	Dec. 31, 2013

Expenditure of Hong Kong Project Co-ordinator (HK\$)

1 st year		2 nd year (if applicable)	
Budget allocated	Unspent balance	Budget allocated	Unspent balance
26,000	1,220	26,000	0

Objective(s) as per original application

1. To explore the storage model design for database systems with the new storage technologies including NAND flash and PCM;
2. To develop energy-efficient indexing and query processing techniques under new storage models;
3. To propose energy-efficient transaction processing methods that leverage fast access and persistency features of PCM;
4. To evaluate the performance of the proposed techniques and methods by combining theoretical analysis and simulation-based experiments.

Exchange activities taken in the whole project duration

Name of Hong Kong traveller	Dates of visit	Address of visiting institution	Purpose of visit
Jianliang Xu	August 5-23, 2012; July 30 - August 8, 2013	Gottlieb-Daimler-Straße 47, 67663 Kaiserslautern, Germany	System modelling and idea exchange; evaluation of research progress and experiment design

Name of German traveller	Dates of visit	Address of visiting institution	Purpose of visit

recorded

(Revision 3/09)

Theo Härder / Yi Ou	April 19-25, 2012; November 20-30, 2013	224 Waterloo Road, Hong Kong Baptist University, Kowloon Tong	Exchange of solutions and ideas; system and algorithm implementation; experiments and performance evaluation
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Details of Report [Please attach relevant document(s)]

i) Outline of proposed research and results obtained

Due to high access performance and price-per-byte considerations, NAND flash memory has been recommended for use as a mid-tier cache in a multi-tier storage system. We identified several weaknesses of the indirect use of flash memory in mid-tier caching. As improvements, we have proposed two new approaches, an indirect approach called LPD (logical page drop) and a native approach called NFA (native flash access). The basic idea is to drop cold pages proactively so that the garbage collection overhead can be minimized. Our experiments demonstrated that both approaches, especially the native one, effectively improve the use of flash memory in the mid-tier cache. NFA reduces the number of garbage collections and block erasures by up to a factor of five and improves the mid-tier throughput by up to 66%.

Phase Change Memory (PCM) is another promising next-generation memory technology with a range of interesting properties: it is non-volatile, bit alterable, and byte addressable. Instead of being used as an external storage solution (like NAND flash memory), PCM is more likely to be used in the main memory system as buffer pools. We have investigated how the database buffer manager can deal with the write endurance problem, which is unique to PCM-based buffer pools. We have designed a family of new buffer algorithms addressing this problem, called wear-aware buffer algorithms, and studied their behaviour using trace-driven simulations.

We have also developed a novel logging scheme named PCMLogging that exploits PCM for both data caching and transaction logging to minimize I/O accesses in disk-based databases. Specifically, PCMLogging caches dirty pages/records in PCM and further maintains an implicit log in the cached updates to support database recovery. By integrating log and cached updates, PCMLogging enables simplified recovery and prolongs PCM lifetime. Furthermore, using PCMLogging, we have designed a wear-leveling algorithm, that evenly distributes the write traffic across the PCM storage space, and a cost-based destaging algorithm that adaptively migrates cached data from PCM to external storage. Compared to classical write-ahead logging (WAL), our trace-driven simulation results revealed up to 1~20X improvement in system throughput.

ii) Significance of research results

With the continuous improvement of CPU clock rates and rapid development of other processor-related technologies (e.g., multi-core, GPU, etc.), the performance gap between processing units and storage devices have been enlarged in recent years. To minimize the gap, an increase of main-memory capacity is required to keep up with the performance growth of processors. At the same time, the explosion of data to be managed also increases the demand on the main memory capacity. As such, there is an urgent need to leverage new storage technologies to optimize the system performance with innovative designs. As demonstrated, our proposed caching and transaction techniques based on NAND flash and PCM storage technologies can substantially reduce the I/O cost and improve the overall system throughput. They require a minimal modification of the existing system architecture and have a good potential to be integrated into real data management systems.

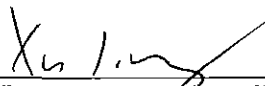
Research output

1. Y. Ou, J. Xu, and T. Härder. "Towards an Efficient Flash-Based Mid-Tier Cache." *Proc. 23rd International Conference on Database and Expert Systems Applications (DEXA '12)*, Vienna, Austria, September 2012, pp. 55-70.
2. Y. Ou, L. Chen, J. Xu and T. Haerder. "Wear-Aware Algorithms for PCM-Based Database Buffer Pools." In *Proc. the Second International Workshop on Big Data Management on Emerging Hardware (HardBD)*, Macau, June 2014.
3. S. Gao, J. Xu, T. Haerder, B. He, B. Choi, H. Hu. "PCMLogging: Optimizing Transaction Logging and Recovery Performance with PCM", Submitted to *IEEE Transactions on Knowledge and Data Engineering (TKDE)*, 2014 (under major revision).

iv) Potential for or impact on further research collaboration

Building on the successful collaboration established during this project, we plan to further investigate PCM-assisted indexing and query processing in hybrid storage models. Since PCM can endure only a limited of writes, a re-design of index structures and related query algorithms has to be considered. Data placement is another issue to be investigated. For example, it would be desirable to use PCM for write-intensive index data and NAND flash for read-intensive application data. We also plan to implement the proposed techniques in an open-source database management system to demonstrate their feasibility. It is of particular interest to incorporate them into SQLite, a database widely used on smartphones, because PCM has already been deployed on mobile handsets.

Signatures and Dates



Hong Kong Project Co-ordinator
Date: June 19, 2014



Hong Kong Institution's Representative
Date: 4 July 2014